WHITE PAPER

USDA Forest Service | Pacific Northwest Region | Umatilla National Forest

WHITE PAPER F14-SO-WP-SILV-26

Is This Stand Overstocked? An Environmental Education Activity[1]

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Originating, growing, and tending stands of trees is called silviculture (silva is the Latin word for forest). Silviculture is a cornerstone of forestry. Someone who is trained and experienced in silviculture is called a silviculturist.

The forestry profession exists to help people get the benefits they want from forests, but forests have limits. Like all living things, trees are restricted in what they can do. A tree species needing well-drained soils cannot survive in a marsh. If seeds require bare soil for germination, no amount of urging will get them to establish on a layer of tree needles.

A silviculturist helps people understand what trees need, why only certain tree species grow in an area, and how stands of trees could be managed to supply people with the forest benefits they want (to meet people's objectives).

Sometimes, what society wants from a forest is for the trees to be left alone to pursue their own destiny. But often, a forester is asked to get involved, particularly when a forest has problems – stands that have been damaged by insects or diseases, stands that don't provide good wildlife habitat, or stands that need to produce more feed for cattle or sheep.

To grow well, a tree needs a place in the sun and some soil to call its own. When trees are crowded and standing too close together, they lack enough sun or water to thrive. Trees without sufficient sun, water, and food (nutrients) become weak – and weak trees are destined to be attacked by bark beetles or root diseases.

[1] White papers are internal reports; they receive only limited review. Viewpoints expressed in this paper are those of the author – they may not represent positions of the USDA Forest Service.

One thing foresters need to know is how many trees are present in a stand. This concept is called stocking. Foresters take measurements to determine how many trees are present now, which is then compared with how many trees there should be (stocking recommendations).

Your task is to take some measurements in a forest stand, and then use the information to figure out if it is overstocked (does the stand have too many trees?).

You can accomplish this task in five steps:

- ✓ First, the whole group will be split up into small teams, and each team will have a helper provided by the Forest Service.
- ✓ Second, each team will move into a portion of the stand and set up a circular plot, using the instructions provided below.
- ✓ Third, the team will use equipment provided by the Forest Service to measure trees occurring on the plot, and record your data on the plot sheets provided in this handout.
- ✓ Fourth, you will summarize your data to come up with an average for the whole plot.
- ✓ Fifth, you will compare your plot information with stocking charts to figure out if the stand is overstocked or not.

My experience is that most folks do not enjoy mathematics. But many jobs require good mathematics skills, and forestry is no exception. The exercises in this handout will show you some of the ways that foresters use mathematics in their work.

Foresters often deal with large land areas. They need to know what kind of trees grow on the area, how many of them there are, and how big they are. Trying to measure every tree on a national forest covering one and half million acres and containing more than 500 million trees would not only be time consuming and expensive, but impossible!

For these and other reasons, foresters only measure part of the forest, a process called sampling. They assume that the measured (sampled) part represents the whole area, which is referred to as the population. Data collected from the sampled part is expanded to provide information for the unsampled portion.

Suppose we need to know the tree stocking levels for a 54-acre tree stand on the Heppner Ranger District. The entire stand (all 54 acres) is our population, but we can't measure every tree because it would take too much time. So the best way to determine the stand's stocking level is to sample it, which is accomplished by establishing plots.

How can we figure out a plot size? By using some mathematical formulas, of course! Previous sampling experience shows that circular plots are easier to use than square ones, so we'll use circular plots to sample our forest stand.

To lay out a plot in the shape of a circle, we must know its radius, which we'll figure out using this formula:

$$\text{Area} = \text{Pi} \times \text{Radius}^2$$

> Note: if you don't know what pi is, here is a short description. Pi does not refer to a dessert pastry (my favorite is cherry pie) – it is the number you get when you divide the distance around a circle (its circumference) by the distance through its middle (the diameter). The distance around the outside of every circle is about three times the distance across it. But it's the "about" part that creates the puzzle of pi. Mathematicians call pi an irrational number because when you divide a circle's circumference by its diameter, the answer comes out in decimals that go on forever without any apparent pattern. Pi begins as 3.14159265, but it never ends. In 1999, a Japanese scientist used a supercomputer to calculate pi to about 206 billion digits, and it still goes on from there. All those digits aren't really necessary to use pi, of course – using only the first ten decimals, you can measure the earth's circumference to within a fraction of an inch. Pi is often shown in textbooks or in formulas using the Greek symbol π.

Let's say that we decide to use a plot covering ¼ of an acre. The total area of an acre is 43,560 square feet. Since we want to use a ¼-acre plot, its area is 43,560 ÷ 4 or 10,890 square feet. We now have enough information to use the formula from the bottom of page 2 to figure out our plot radius.

$$
\begin{aligned}
\text{Area} &= \text{Pi} \times \text{Radius}^2 \\
10{,}890 \text{ square feet} &= 3.1416 \times \text{Radius}^2 \\
10{,}890 \text{ square feet} \div 3.1416 &= \text{Radius}^2 \\
3{,}466.39 \text{ square feet} &= \text{Radius}^2 \\
\sqrt{3{,}466.39} \text{ square feet} &= \text{Radius} \\
58.9 \text{ feet} &= \text{Radius}
\end{aligned}
$$

So, this means that each ¼-acre plot would be installed as a circle with a radius of 58.9 feet.

For your exercise today, each group will use the same plot size (and it might not be ¼ acre); a plot size will be selected by your group leader during the field exercise.

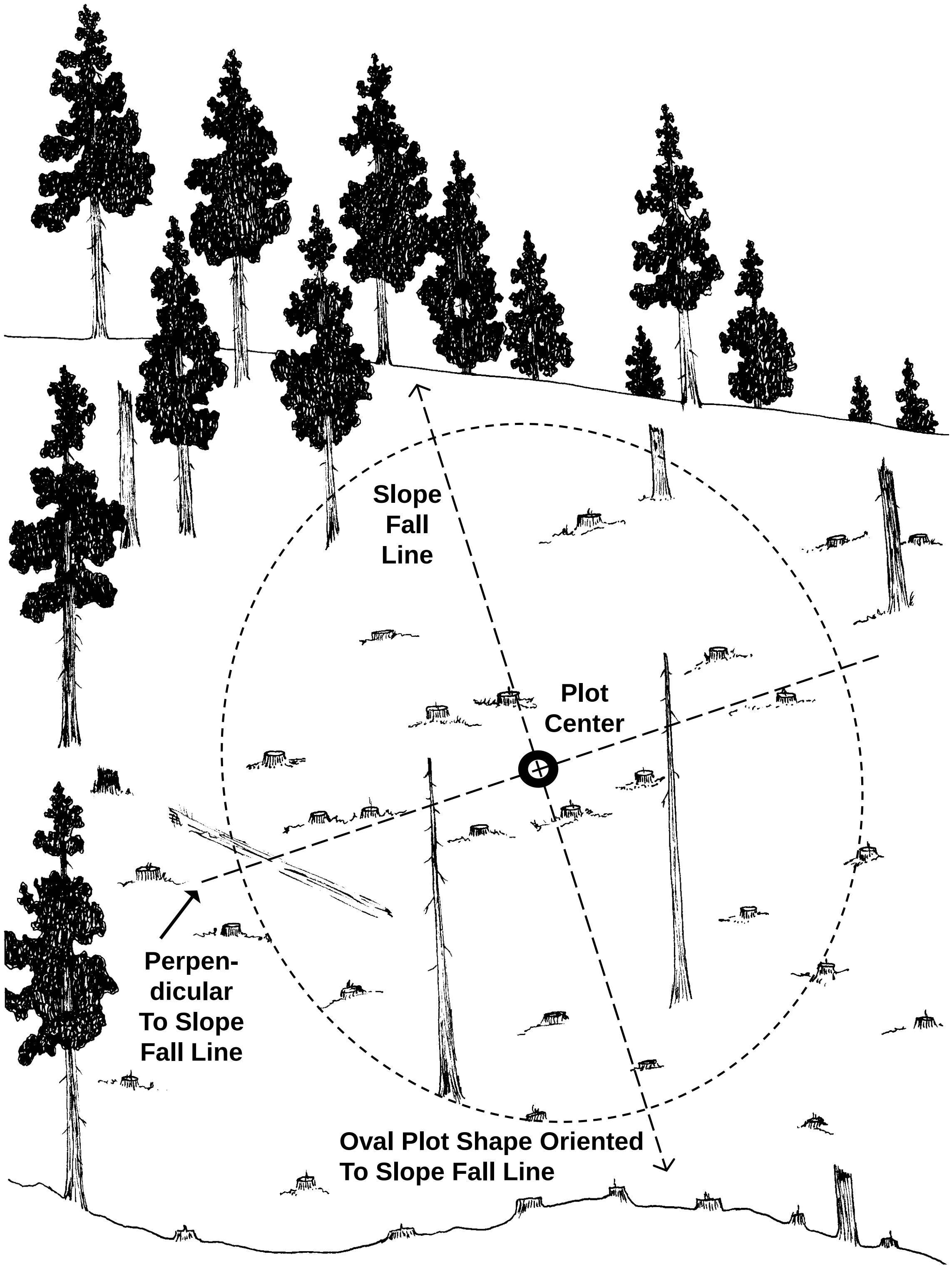
Each team will use a wooden or wire stake to mark the plot center, and you will then use a measuring tape to determine the plot boundaries by measuring out a radius in several directions from the stake.

Rather than have each group figure out the size of your plot radius by using calculators and the formula for a circle (like the example above), I have done the calculations for you and the plot areas and plot radiuses are provided in this table:

Table 1: Plot size, area, and radius

Plot Size (Acres)	Plot Area (Square Feet)	Plot Radius (Feet)
1/4	10,890	58.9
1/5	8,712	52.7
1/10	4,356	37.2
1/20	2,178	26.3
1/50	871	16.7
1/100	436	11.8
1/250	174	7.5
1/300	145	6.8
1/500	87	5.3
1/1000	44	3.7

If the ground near your plot center is absolutely flat, then the plot is a perfect circle with a radius as shown in the table above. The problems start when you are working on a hill because the plot's radius then varies, depending on the steepness of the hill. By projecting a plot's radius on a steep hillside, we see that it becomes oval in shape, not circular:



On sloping ground, plots have an oval shape with their long axis parallel to the slope (called the "slope fall line"). Note that a line perpendicular to the slope forms a right angle with the slope fall line. Plots on sloping ground need to have their radius adjusted using a factor that converts slope distance to what is called horizontal distance.

How do we adjust the radius of a plot that occurs on sloping ground? Well, you could figure out the adjusted radius using trigonometry (secants), but most foresters just carry around something called a slope correction table.

Here is part of the slope correction table for slopes ranging up to 61 percent:

Table 2: Slope correction factors

Slope Percent	Correction Factor
0 – 9	1.00
10 – 17	1.01
18 – 22	1.02
23 – 26	1.03
27 – 30	1.04
31 – 33	1.05
34 – 36	1.06
37 – 39	1.07
40 – 42	1.08
43 – 44	1.09
45 – 47	1.10
48 – 49	1.11
50 – 51	1.12
52 – 53	1.13
54 – 55	1.14
56 – 57	1.15
58 – 59	1.16
60 – 61	1.17

Now, let's use table 2's slope correction factors to figure out if some trees near our plot edge are "in or out" (inside or outside of the plot radius). These trees near the plot edge are referred to as borderline trees. Here is a way to measure borderline trees:

1. Use an instrument called a clinometer to measure the slope percent from the center (side) of a borderline tree to the plot center (let's say that it is 30 percent).
2. Find a slope correction factor in table 2 for the slope percent you just measured (the correction factor is 1.04 for 30 percent).
3. Multiply the correction factor by the plot radius. This is called the corrected radius. For a ¼-acre plot, the result is: 58.9 feet × 1.04 = 61.3 feet.
4. Measure the slope distance from the center (side) of the tree to the plot center. If the measured distance is less than the corrected radius (61.3 feet in this example), then the tree is in; if the measured distance is more, the tree is out.

MEASURING TREE DIAMETER

Now that we know how to figure out which trees are in or out of the plot, we need to learn how to measure the size of trees that are in on the plot. Tree size has two dimensions – how big around (tree circumference), and how tall (tree height).[2] For this field exercise, we need to find out how big around each tree is.

There are two main ways we can describe the size of round objects like tree stems:

- We can measure the circumference, the distance around the outside of their trunk, or
- We can measure the circumference and convert it to diameter, which is the distance through the middle of a tree's trunk.

Foresters use special measuring tapes that show a tree's circumference on one side, and its equivalent diameter on the other side. How is this done? Actually, it's easy to do because circumference and diameter are closely related:

$$\text{Circumference} = \text{Pi} \times \text{Diameter}$$

$$\text{Diameter} = \text{Circumference} \div \text{Pi}$$

One final thought about measuring tree diameter. By historical convention, diameter is measured at "breast height", which is defined as 4½ feet above the ground surface on the uphill side of the tree. It will hereafter be referred to as DBH (diameter at breast height) – welcome to the world of forestry jargon! [DBH is used because measuring diameter at 4½ feet is easier than bending down to measure it at ground line.]

CALCULATING BASAL AREA

Tree count tells us how many trees are present in an area, but a tree count does not account for differences in tree size. If a count shows 500 trees per acre, do they occur as 1-foot-tall seedlings or as 40-foot-tall trees? It makes a huge difference because 500 1-foot-tall seedlings per acre might be okay, but 500 large trees per acre almost always presents a problem.

To deal with this size issue, foresters use a measurement called basal area, which gets at the "bulk" of a tree. Basal area is a hard concept to understand. It is the cross-sectional area of a tree at breast height (DBH), in square feet, as though we cut the tree off at DBH and then wanted to calculate the surface area of the top of the stump (the flat part).

Here is the formula for calculating the basal area (BA) of a single tree, in square feet:

$$\text{BA} = \text{Pi} \times (\text{DBH}/24)^2$$

> [Have you noticed yet that most mathematical formulas pertaining to circles, including round objects like tree stems, use pi?]

[2] Many tasks require foresters to measure tree height. To evaluate stocking, tree height is not needed, so the process for measuring tree height will not be described in this white paper.

Rather than ask you to use a formula to calculate basal area for each tree on the plot, I will provide the basal area values in a look-up table:

Table 3: Basal area by DBH

DBH (Inches)	Basal Area (Square Feet)
1	0.01
2	0.02
3	0.05
4	0.09
5	0.14
6	0.20
7	0.27
8	0.35
9	0.44
10	0.55
11	0.66
12	0.79
13	0.92
14	1.07
15	1.23
16	1.40
17	1.58
18	1.77
19	1.97
20	2.18
21	2.41
22	2.64
23	2.89
24	3.14
25	3.41
26	3.69
27	3.98
28	4.28
29	4.59
30	4.91
32	5.59
34	6.31
36	7.07

So, here’s your process for sampling a stand and determining if it is overstocked:

1. Locate a plot area, and pound in a stake to mark its center.
2. Decide which plot size will be used, and find the radius for that plot in table 1.
3. Is a tree in the plot? Stretch out a measuring tape from the plot center stake in a full 360° circle to determine which trees are in your plot. Trees in the plot are called sample trees. Each sample tree is numbered and recorded on the plot form. Note: if your plot occurs on sloping ground, and if there is limited time for the field exercise, don’t worry about correcting for slope. However, accurate plot measurements would always convert slope distance to horizontal distance.
4. What is the species of tree? For all sample trees, record the species on the plot form.
5. What is the DBH? For all sample trees, measure their diameter with a diameter tape (round off to the nearest whole inch), and record the value on the plot form.
6. What is the basal area of each sample tree? For all sample trees, record their basal area on the plot form (hint: look up the basal area value, by DBH, in table 3).
7. What is the plot’s total basal area? Use your calculator to add up the values in the basal area column on the form, and then record the answer in the space provided.
8. How many trees per acre does the stand have? Here’s how to do this: take the number of sample trees and multiply it by the plot expansion factor.

> Note: when you sample a portion of an acre, and then want to expand the sample data so it represents a whole acre, the sample values must be multiplied by the denominator of the plot size. Examples: for a 1/10-acre plot, each sample tree represents 10 trees (the denominator value); for a 1/20-acre plot, each sample represents 20 trees, etc. The denominator value is referred to as the “plot expansion factor.”

9. What is the stand’s basal area? Here’s how to do this: take the plot’s total basal area answer and multiply it by the plot expansion factor.
10. Calculate an average stand diameter. Here’s how to do this: take the square root of stand basal area divided by stand trees per acre, and multiply the answer by 13.54 (each team should ask their leader to assist with this calculation).

    Formula: $\sqrt{\text{Stand BA/Stand TPA}} \times 13.54$ = Average stand diameter (QMD)
11. Now you are ready to decide if the stand is overstocked or not! Take the average stand diameter and the stand basal area answers, and use them with the stocking charts (at the end of this handout) to find where your stand falls on the charts.
12. Here’s how to interpret the chart position:
    - Between the blue and green lines: not overstocked; **the trees are happy**.
    - Between the green and red lines: moderately overstocked; **stand is crowded and the trees are cranky**.
    - Between the red and black lines: greatly overstocked; **stand is very dense and trees are definitely stressed out**.

EXAMPLE PLOT (Plot size = 1/10 acre; radius = 37.2 feet)

Sample Tree	Species	Diameter (Inches)	Basal Area (Square Feet)
1	Ponderosa pine	22	2.6
2	Ponderosa pine	27	4.0
3	Western larch	18	1.8
4	Douglas-fir	29	4.6
5	Western larch	12	0.8
6	Douglas-fir	8	0.3
7	Western larch	14	1.1
8	Ponderosa pine	9	0.4
9	Ponderosa pine	15	1.2
10	Douglas-fir	16	1.4
	TOTAL		18.2

1. Trees per acre: 100 (number of sample trees × expansion factor) (10 × 10)
2. Basal area per acre: 182 (total plot BA × expansion factor) (18.2 × 10)
3. Average stand diameter (QMD): 18 (use formula in item 10 on page 9)
4. Stocking status for ponderosa pine: **greatly overstocked**
5. Stocking status for western larch: **greatly overstocked**
5. Stocking status for Douglas-fir: **greatly overstocked**
6. Stocking status for grand fir: **not overstocked**

LET'S SUMMARIZE

What have you learned from this exercise?

- How forestry and silviculture serves society.
- How to figure out the radius of a circular plot after being given its area.
- How to adjust a plot radius to account for sloping ground.
- That many mathematical formulas involving circles use pi, a special never-ending constant that we round off to 3.1416.
- How to measure the diameter of trees.
- How to calculate basal area.
- How to establish and measure a sample plot.
- How to use stocking charts to figure out if a stand is overstocked or not.

PLOT FORM

Plot number ____________

Plot size _________ Plot radius ___________ Expansion factor ___________

Sample Tree Num.	Species	Diameter (Inches)	Basal Area (Square Feet)
		Total	

1. Trees per acre: __________ (number of sample trees × expansion factor)
2. Basal area per acre: __________ (total plot BA × expansion factor)
3. Average stand diameter (QMD): __________ (see item #10 on page 9)
4. Stocking status for ponderosa pine: ____________________
5. Stocking status for western larch: ____________________
6. Stocking status for Douglas-fir: ____________________
7. Stocking status for grand fir: ____________________

PLOT FORM

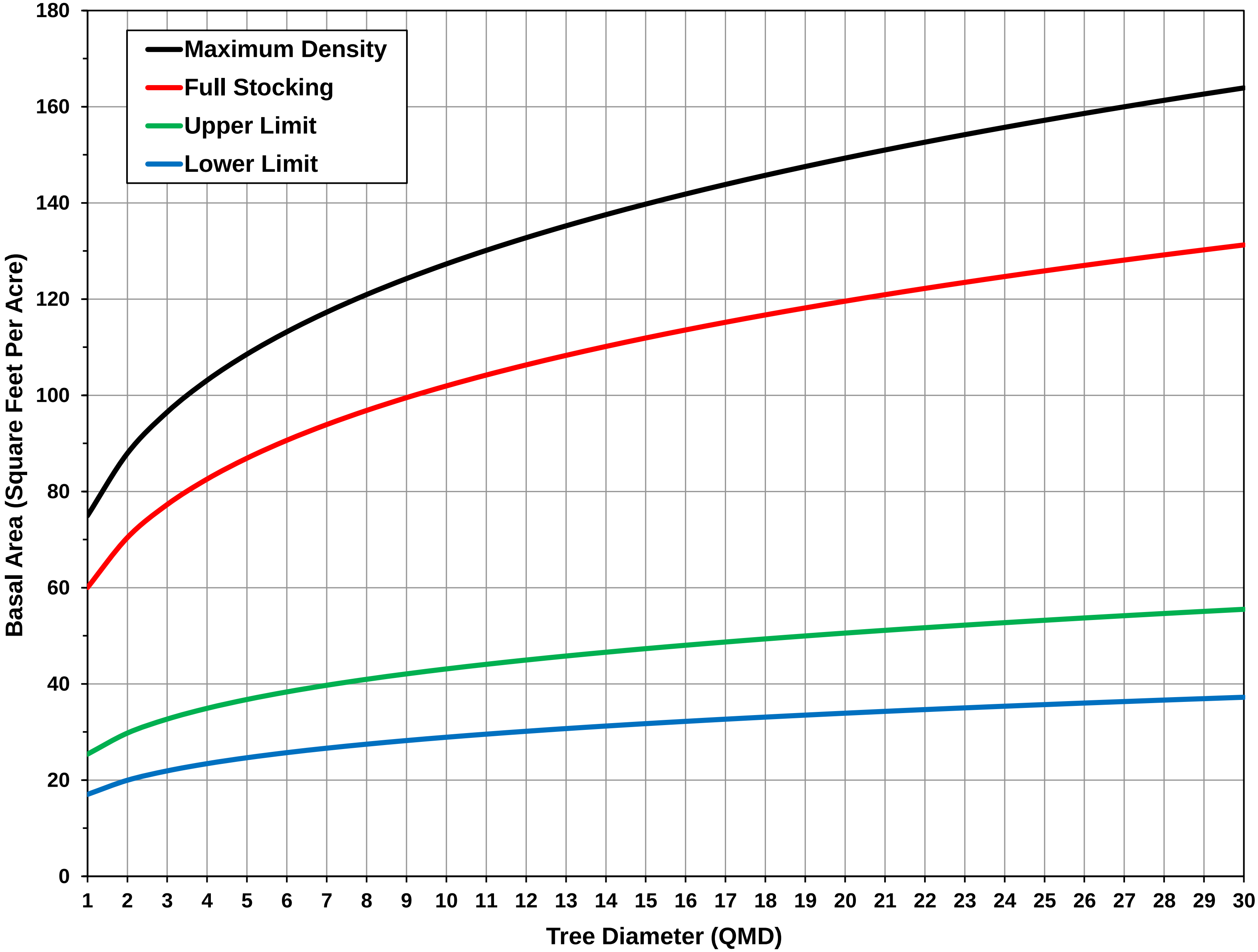
Plot number ____________

Plot size _________ Plot radius ___________ Expansion factor ___________

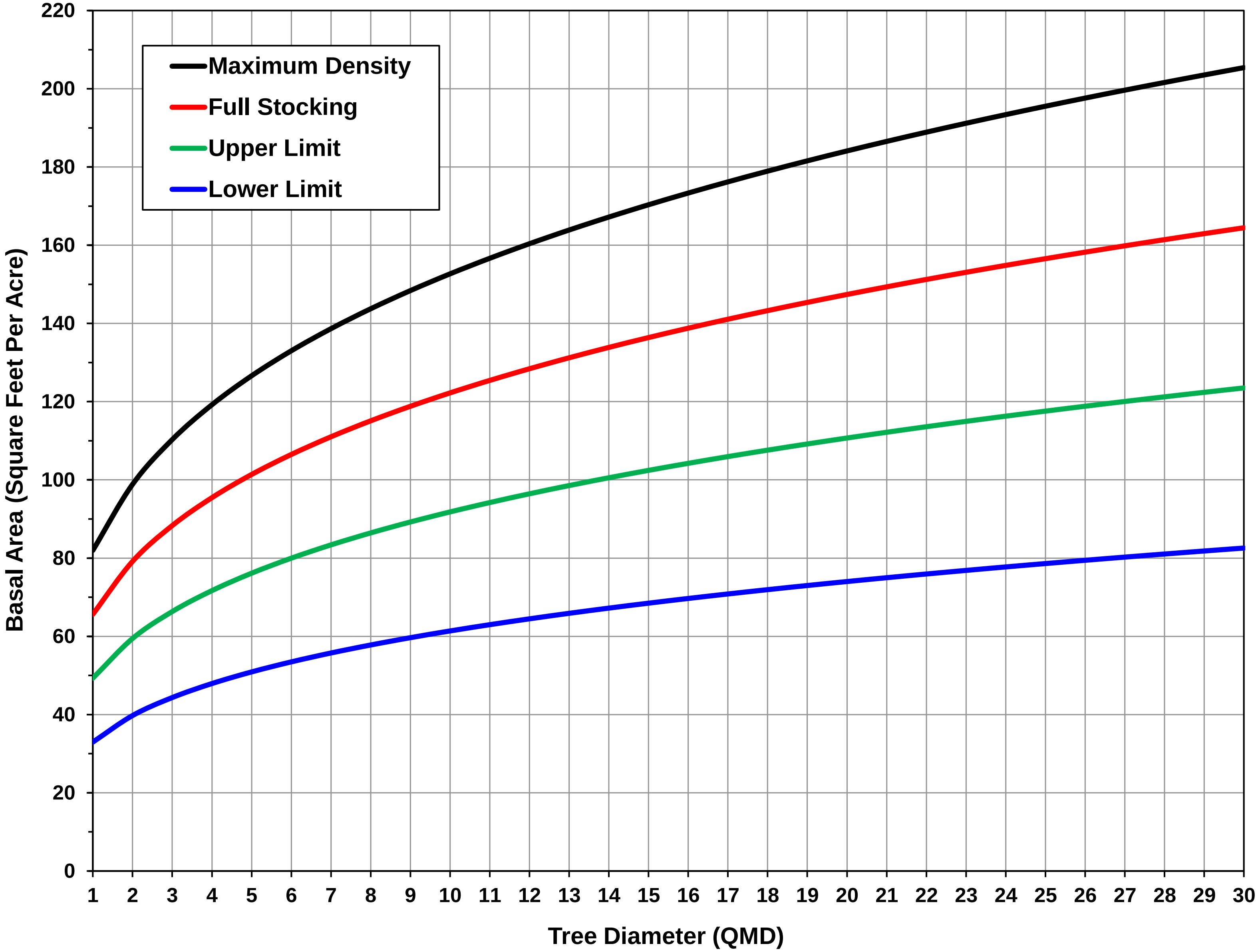
Sample Tree Num.	Species	Diameter (Inches)	Basal Area (Square Feet)
		Total	

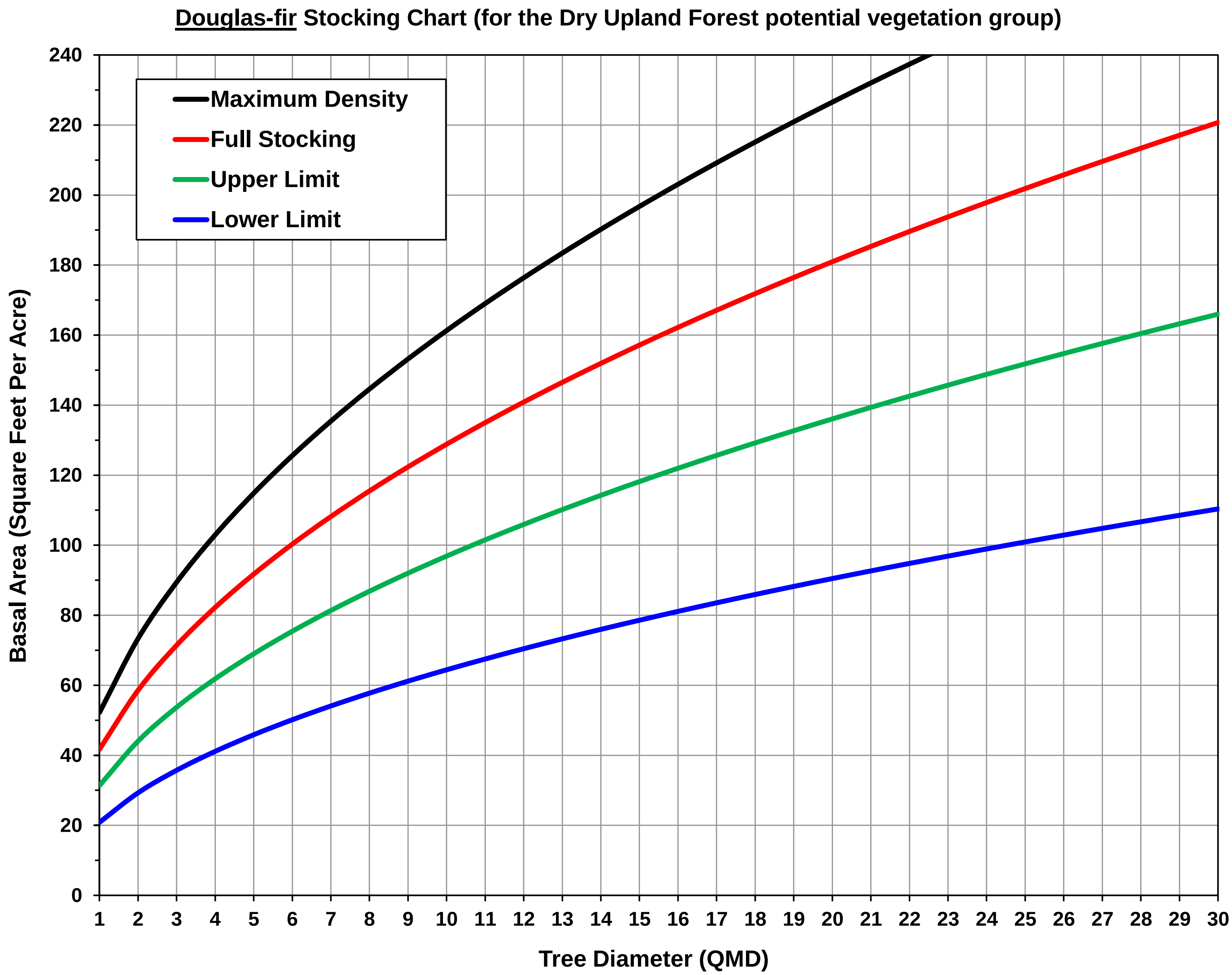
1. Trees per acre: __________ (number of sample trees × expansion factor)
2. Basal area per acre: __________ (total plot BA × expansion factor)
3. Average stand diameter (QMD): __________ (see item #10 on page 9)
4. Stocking status for ponderosa pine: ____________________
5. Stocking status for western larch: ____________________
6. Stocking status for Douglas-fir: ____________________
7. Stocking status for grand fir: ____________________

Ponderosa Pine Stocking Chart (for the Dry Upland Forest potential vegetation group)

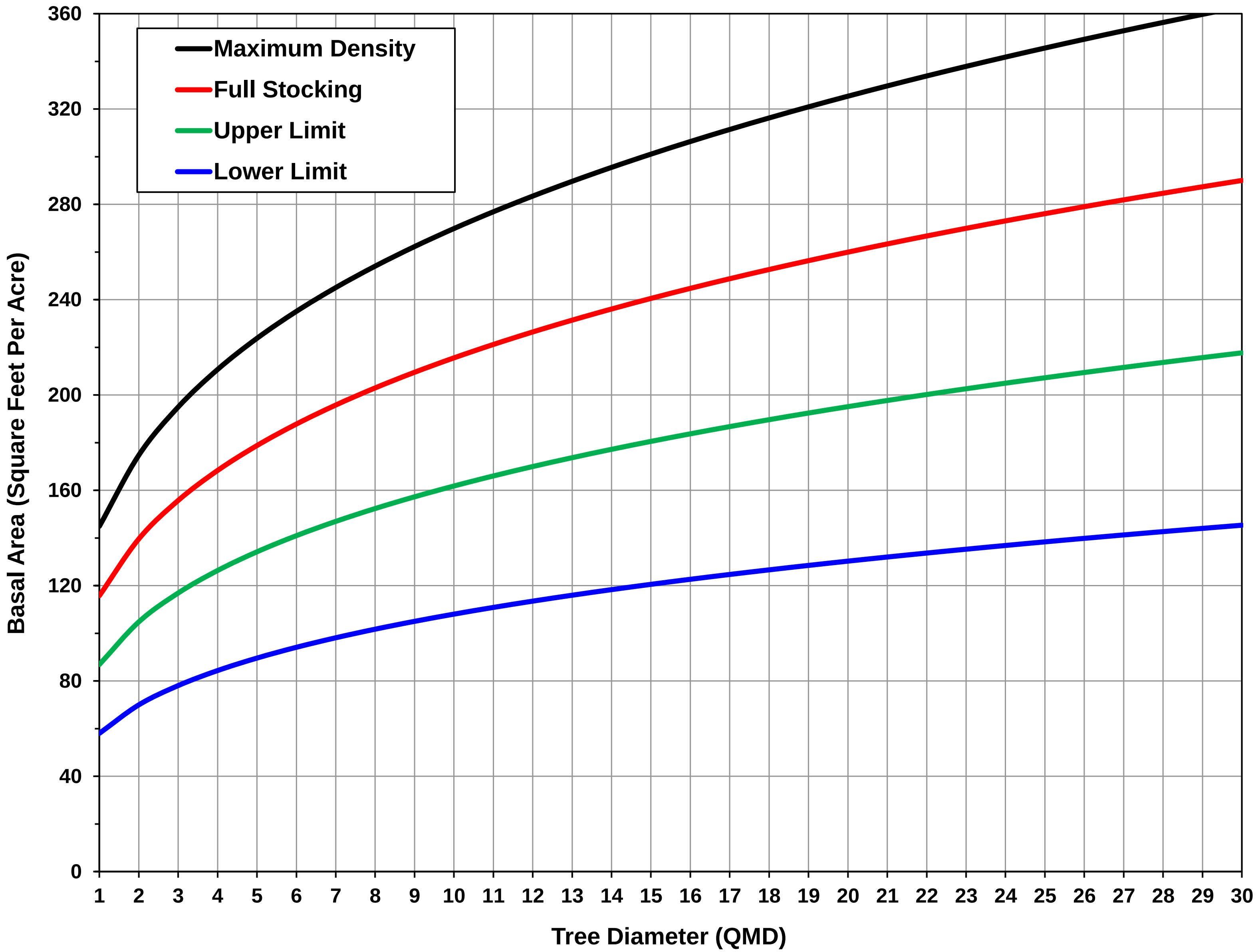


Western Larch Stocking Chart (for the Dry Upland Forest potential vegetation group)




Douglas-fir Stocking Chart (for the Dry Upland Forest potential vegetation group)
Maximum Density
Full Stocking
Upper Limit
Lower Limit
Basal Area (Square Feet Per Acre)
0
20
40
60
80
100
120
140
160
180
200
220
240
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Tree Diameter (QMD)

Grand Fir Stocking Chart (for the Dry Upland Forest potential vegetation group)



APPENDIX: SILVICULTURE WHITE PAPERS

White papers are internal reports, and they are produced with a consistent formatting and numbering scheme – all papers dealing with Silviculture, for example, are placed in a silviculture series (Silv) and numbered sequentially. Generally, white papers receive only limited review and, in some instances pertaining to highly technical or narrowly focused topics, the papers may receive no technical peer review at all. For papers that receive no review, the viewpoints and perspectives expressed in the paper are those of the author only, and do not necessarily represent agency positions of the Umatilla National Forest or the USDA Forest Service.

Large or important papers, such as two papers discussing active management considerations for dry and moist forests (white papers Silv-4 and Silv-7, respectively), receive extensive review comparable to what would occur for a research station general technical report (but they don't receive blind peer review, a process often used for journal articles).

White papers are designed to address a variety of objectives:

(1) They guide how a methodology, model, or procedure is used by practitioners on the Umatilla National Forest (to ensure consistency from one unit, or project, to another).

(2) Papers are often prepared to address ongoing and recurring needs; some papers have existed for more than 20 years and still receive high use, indicating that the need (or issue) has long standing – an example is white paper #1 describing the Forest's big-tree program, which has operated continuously for 25 years.

(3) Papers are sometimes prepared to address emerging or controversial issues, such as management of moist forests, elk thermal cover, or aspen forest in the Blue Mountains. These papers help establish a foundation of relevant literature, concepts, and principles that continuously evolve as an issue matures, and hence they may experience many iterations through time. [But also note that some papers have not changed since their initial development, in which case they reflect historical concepts or procedures.]

(4) Papers synthesize science viewed as particularly relevant to geographical and management contexts for the Umatilla National Forest. This is considered to be the Forest's self-selected 'best available science' (BAS), realizing that non-agency commenters would generally have a different conception of what constitutes BAS – like beauty, BAS is in the eye of the beholder.

(5) The objective of some papers is to locate and summarize the science germane to a particular topic or issue, including obscure sources such as master's theses or Ph.D. dissertations. In other instances, a paper may be designed to wade through an overwhelming amount of published science (dry-forest management), and then synthesize sources viewed as being most relevant to a local context.

(6) White papers function as a citable literature source for methodologies, models, and procedures used during environmental analysis – by citing a white paper, specialist reports can include less verbiage describing analytical databases, techniques, and so forth, some of which change little (if at all) from one planning effort to another.

(7) White papers are often used to describe how a map, database, or other product was developed. In this situation, the white paper functions as a 'user's guide' for the new

product. Examples include papers dealing with historical products: (a) historical fire extents for the Tucannon watershed (WP Silv-21); (b) an 1880s map developed from General Land Office survey notes (WP Silv-41); and (c) a description of historical mapping sources (24 separate items) available from the Forest's history website (WP Silv-23).

The following papers are available from the Forest's website: Silviculture White Papers

Paper #	Title
1	Big tree program
2	Description of composite vegetation database
3	Range of variation recommendations for dry, moist, and cold forests
4	Active management of dry forests in the Blue Mountains: silvicultural considerations
5	Site productivity estimates for upland forest plant associations of the Blue and Ochoco Mountains
6	Fire regimes of the Blue Mountains
7	Active management of moist forests in the Blue Mountains: silvicultural considerations
8	Keys for identifying forest series and plant associations of the Blue and Ochoco Mountains
9	Is elk thermal cover ecologically sustainable?
10	A stage is a stage is a stage…or is it? Successional stages, structural stages, seral stages
11	Blue Mountains vegetation chronology
12	Calculated values of basal area and board-foot timber volume for existing (known) values of canopy cover
13	Created opening, minimum stocking level, and reforestation standards from the Umatilla National Forest land and resource management plan
14	Description of EVG-PI database
15	Determining green-tree replacements for snags: a process paper
16	Douglas-fir tussock moth: a briefing paper
17	Fact sheet: Forest Service trust funds
18	Fire regime condition class queries
19	Forest health notes for an Interior Columbia Basin Ecosystem Management Project field trip on July 30, 1998 (handout)
20	Height-diameter equations for tree species of the Blue and Wallowa Mountains
21	Historical fires in the headwaters portion of the Tucannon River watershed
22	Range of variation recommendations for insect and disease susceptibility
23	Historical vegetation mapping
24	How to measure a big tree
25	Important insects and diseases of the Blue Mountains
26	Is this stand overstocked? An environmental education activity
27	Mechanized timber harvest: some ecosystem management considerations
28	Common plants of the south-central Blue Mountains (Malheur National Forest)

Paper #	Title
29	Potential natural vegetation of the Umatilla National Forest
30	Potential vegetation mapping chronology
31	Probability of tree mortality as related to fire-caused crown scorch
32	Review of the “Integrated scientific assessment for ecosystem management in the interior Columbia basin, and portions of the Klamath and Great basins” – forest vegetation
33	Silviculture facts
34	Silvicultural activities: description and terminology
35	Site potential tree height estimates for the Pomeroy and Walla Walla ranger districts
36	Tree density protocol for mid-scale assessments
37	Tree density thresholds as related to crown-fire susceptibility
38	Umatilla National Forest Land and Resource Management Plan: forestry direction
39	Updates of maximum stand density index and site index for the Blue Mountains variant of the Forest Vegetation Simulator
40	Competing vegetation analysis for the southern portion of the Tower Fire area
41	Using General Land Office survey notes to characterize historical vegetation conditions for the Umatilla National Forest
42	Life history traits for common conifer trees of the Blue Mountains
43	Timber volume reductions associated with green-tree snag replacements
44	Density management field exercise
45	Climate change and carbon sequestration: vegetation management considerations
46	The Knutson-Vandenberg (K-V) program
47	Active management of quaking aspen plant communities in the northern Blue Mountains: regeneration ecology and silvicultural considerations
48	The Tower Fire…then and now. Using camera points to monitor postfire recovery
49	How to prepare a silvicultural prescription for uneven-aged management
50	Stand density conditions for the Umatilla National Forest: a range of variation analysis
51	Restoration opportunities for upland forest environments of the Umatilla National Forest
52	New perspectives in riparian management: Why might we want to consider active management for certain portions of riparian habitat conservation areas?
53	Eastside Screens chronology
54	Using mathematics in forestry: an environmental education activity
55	Silviculture certification: tips, tools, and trip-ups
56	Vegetation polygon mapping and classification standards: Malheur, Umatilla, and Wallowa-Whitman national forests
57	The state of vegetation databases on the Malheur, Umatilla, and Wallowa-Whitman national forests

REVISION HISTORY

October 2011: The first version of this white paper was prepared for use with Mr. Kevin Steinmetz's elementary school class in John Day, Oregon. It was designed to show students how mathematics skills are used in one particular profession (forestry in this instance). It was revised many times since 1990 as it was used for other environmental education activities, such as outdoor schools and the Fire and Fuels Camp hosted by the Heppner Ranger District of the Umatilla National Forest.